SMART STRUCTURES

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force

OBJECTIVE: The goal of this project was to support the Smart Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications.

SUMMARY: The major efforts were in the development of the Smart Structures Laboratory and the validation of MRJ piezoelectric finite element model. The Ultra Quiet Vibration Isolation Platform, developed by CSA Engineering, is operational. System identification of the platform was completed. Coupling between smart struts was significant. NPS space truss was assembled and modal testing of the truss was also completed. Proof mass actuators and piezoelectric struts were procured. Active vibration control of a flexible beam using Modular Control Patch was performed. The investigation included single-mode and multi-mode vibration suppression and Positive Position Feedback control robustness. An experiment using a beam with shape memory alloy wires, fabricated by Lockheed Martin, was developed to demonstrate the active shape control. A Fiber Bragg Grating Optic sensor, manufactured by Bragg Photonics, was tested for the applications to vibration control and shape control. MRJ piezoelectric finite element model was implemented with the user-modifiable NASTRAN V.69. TRW Composite Smart Strut was used as a test article to validate the model. Experimentally, free displacement and blocked force were measured and compared with the analytical predictions from the model. Free displacement measurements were in good agreement with the analytical predictions. However, there was a significant difference between the blocked force measurements and the analytical predictions. Part of the difference is attributed to the flexibility of the test fixture, resulting in not providing ideal boundary condition for the blocked force measurements.

PUBLICATIONS:

Agrawal B. and Treanor, K., "Optimal Placement of Piezoceramic Actuators for Shape Control of a Beam," IAF-97-I.602, *Proceedings of the 48th International Astronautical Congress*, Turin, Italy, 6-10 October 1997.

Agrawal B. and Elshafei, M.A., "Shape Control of Composite Material Plates Using Piezoelectric Actuators," Vol. 3241, *Proceedings of Far East and Pacific Rim Symposium on Smart Materials, Structures, and MEMS*, Adelaide, Australia, 10-13 December 1997.

Meyer, J., Harrington, W., Agrawal, B., and Song. G., "Vibration Suppression of a Spacecraft Flexible Appendage Using Smart Materials," to appear in the *Journal of Smart Materials and Structures*, February 1998.

Agrawal, B. and Treanor, K., "Shape Control of a Beam Using Piezoelectric Actuators," to be published in the *Journal of Smart Materials and Structures*, special issue on Smart Structures for Space, September 1998.

Agrawal, B., Elshafei, M., and Song, G., "Adaptive Antenna Shape Control," accepted for publication in *Acta Astronautica Journal.*

THESES DIRECTED:

Andberg, B.K., "Modal Testing and Analysis of the NPS Space Truss," Master's Thesis, Naval Postgraduate School, September 1997.

Beavers, G.D., "System Identification of an Ultra-Quiet Vibration Isolation Platform," Master's Thesis, Naval Postgraduate School, June 1997.

Schmidt, S.P., "Active Vibration Control of Flexible Structures Using the Modular Control Patch," Engineer's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Smart Materials, Adaptive Structures, Vibration Isolation

SPACECRAFT SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: The goal of this project was to develop four spacecraft laboratories at NPS: FLTSATCOM Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory. It is a continuing project.

SUMMARY: During the reporting period, significant progress has been made in several areas. In the Spacecraft Attitude Dynamics and Control Laboratory, implementation of the dSPACE Real Time Control System on the NPS Flexible Spacecraft Simulator (FSS) has been successfully completed and the FSS has been made operational. The Computational Spacecraft Design Laboratory was upgraded both in hardware and software, including Pro/ENGINEER, Pro/Mechanica, MSC/Nastran and COSMOS/M Engineer. Three spacecraft design projects were completed. The mission for the first project was to investigate three asteroids in the main belts. The project was done under AIAA/Lockheed Martin Graduate Competition and won second position. The second project was on a medium earth orbit UHF satellite constellation. This project was sponsored by the Naval Space Command and was in direct support of DoD's effort to analyze alternative solutions for the replacement of the UHF Follow-on (UFO) constellation. The third project was EHF satellite with a classified payload.

PUBLICATIONS:

Agrawal, B., Song, G., and Buck, N., "Slew Maneuvers of Flexible Spacecraft Using Input Shaping and Pulse-Width Pulse-Frequency Modulated Thrusters," IAF-97-A.2.09, *Proceedings of the 48th International Astronautical Congress*, Turin, Italy, 6-10 October 1997.

Agrawal, B., McClelland, R., and Song, G., "Attitude Control of Flexible Spacecraft Using Pulse-Width Frequency Modulated Thrusters," accepted for publication in *Space Technology Journal*.

Song, G., Buck, N., and Agrawal, B., "Spacecraft Vibration Using Pulse-Width Pulse Frequency Modulated Input Shaper," *Proceedings of AIAA Guidance, Navigation, and Control Conference*, New Orleans, LA, 11-13 August 1997.

Yale, G. and Agrawal, B., "A Lyapunov Controller for Cooperative Space Manipulators," accepted for publication in AIAA *Journal of Guidance, Control, and Dynamics.*

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Spacecraft Design, Spacecraft Attitude Control, Space Manipulator

MILITARY USE OF COMMUNICATIONS SATELLITE SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Institute of Joint Warfare Analysis-Naval Postgraduate School

OBJECTIVE: The goal of the project was to aid the military communications planners in the challenging task of providing enhanced communications capacity in the environment of shrinking budgets.

SUMMARY: During the reporting period, the NPS research team, including four students, has worked very closely with DoD Mobile User Study Joint Integrated Teams. The objectives of these Joint Integrated Teams are to define the requirements for Mobile Users, system engineering, and acquisition strategy for the future DoD UHF satellite system. The NPS team had taken an important role on two major tasks. First task was the primary responsibility for the preliminary design of MEO UHF Spacecraft system. The second task was the payload design for GEO UHF Spacecraft System. Both tasks have been completed.

THESES DIRECTED:

Homan, N.M., "A Military UHF Communications Satellite Design for the User on the Move," Master's Thesis, Naval Postgraduate School, December 1997.

Stone, C.R., "Integration of Commercial Mobile Satellite Services into Naval Communications," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Communications Satellites, Mobile Communications, Satellite Architecture

NPS AIRCRAFT SURVIVABILITY SUPPORT

Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) and Naval Postgraduate School

OBJECTIVE: The objective of this effort is to continue the technical and educational support provided to the JTCG/AS for the past 24 years by developing educational material, presenting short courses, and conducting research and performing analyses in aircraft combat survivability. The accomplishments during CY97 are given below.

SUMMARY: (1) Educational Materials: Professor Ball continued the development of the second edition of his AIAA textbook, "The Fundamentals of Aircraft Combat Survivability Analysis and Design," published by the American Institute of Aeronautics and Astronautics in 1985, during CY97. Progress in CY97 consisted of improved rough drafts of the front material and Chapter 1, "An Introduction to the Aircraft Combat Survivability Discipline." The second rough draft of Chapter 3, "The Missions, the Threats, and the Treat Effects," was developed. A new Appendix entitled, "Probability Theory and Its Application to Survivability Assessment," was started, and a very large set of questions for each chapter and appendix of the textbook were developed. (2) Distance Learning: The course, AA 3251, "Aircraft Combat Survivability" was presented to the Naval Air Warfare Center, Weapons Division, China Lake, and the Naval Air Warfare Center, Aircraft Division, Pax River, during the Winter Quarter, 1996/97 as a Distance Learning course. (3) Research Projects: Several research projects were finished during CY97. These included: (a) a study of the vulnerability reduction technology used on modern tactical fixed-wing aircraft, with particular emphasis of the Joint Strike Fighter (JSF); (b) a study of the effect of on-board electronic countermeasure (ECM) equipment on missile miss distance and aircraft survivability; (c) the development of a generic endgame model that can be used to determine the increase in survivability due to an increase in missile miss distance; and (d) the development of a robust model to determine the effectiveness of signature reduction in conjunction with electronic attack in the form of on-board ECM.

CONFERENCE PRESENTATION:

Ball, Robert E., "Service Response to Live Fire Test and Evaluation Requirements," ADPA Live Fire Test and Evaluation Conference-10 Years and Counting, Lawrence Livermore National Laboratory, Livermore, CA, 13-17 January 1997.

THESES DIRECTED:

Adams, Christopher A., "Vulnerability Reduction of Modern Tactical Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

Barrie, Stephen K., "A Study of the Effects of On-Board Electronic Countermeasures (ECM) on the Combat Survivability of Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

Brennan, Sean P., "Educational Materials for the Implementation of Survivability in Combat Aircraft Design," Master's Thesis, Naval Postgraduate School, March 1997.

Flachsbart, Brian M., "A Robust Methodology to Evaluate Aircraft Survivability Enhancement Due to Combined Signature Reduction and On-Board Electronic Attack," Master's Thesis, Naval Postgraduate School, June 1997.

Rippe, Carlos M., "A Study of the Endgame Between a Proximity-Fuzed High Explosive Warhead on a Guided Missile and an Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Electronic Warfare, Modeling and Simulation

KEYWORDS: Aircraft, Survivability, Weapons, Lethality

NPS/NAVAIR SURVIVABILITY AND LETHALITY ASSESSMENT CENTER

Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVES: The objectives of this research project are: (1) to develop and improve the Survivability and Lethality Assessment Center (SLAC) within the NPS Wargaming Analysis & Research Laboratory (WARLAB), and (2) to use the SLAC to conduct survivability and lethality studies. The computer programs in the center are available to the students and faculty at NPS for research in specific survivability and lethality topics on land, sea, air, and space targets as well as research on the programs themselves.

SUMMARY: The major accomplishment in CY97 was the use of the SLAC to determine the type of air target signature modeling and target tracking that is used in the Enhanced Surface-to-Air Missile (ESAM) program.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation

KEYWORDS: Aircraft, Air Defense, Survivability, Lethality, Missiles, Guns

SPACE PROPULSION AND THERMAL CONTROL

O. Biblarz, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: This effort represents activity in applications of importance to space. The arc-jet is used for electric propulsion and PANSAT is an NPS satellite which is undergoing thermal analysis.

SUMMARY: The anode of the arc jet is usually the first component to fail in such thrustors. The anode region is defined as a highly nonequilibrium region which is composed of a nonneutral region or sheath and of an ambipolar region. A

continuum description of the anode region for steady state, isothermal conditions with two- and three-body recombination has been sought in conjunction with Professor C. L. Frenzen of the Department of Mathematics. One-dimensional description which was looked at has so far eluded any satisfactory solution. With respect to PANSAT, a thermal model of the spacecraft has been used to simulate its behavior under given thermal environments and boundary conditions so that temperature predictions can be made. This effort was undertaken in conjunction with Professor Ashok Gopinath of the Department of Mechanical Engineering and Mr. Dan Sakoda of the Space Systems Academic Group.

PUBLICATION:

Biblarz, O. and Bell, W.J., "Thermionic Arc Breakdown in Small Discharge Gaps: Model and Applications," to appear in *1998 IEEE Transactions on Industry Applications*, March/April 1998.

THESES DIRECTED:

Horner, B., "Anode Fall as Relevant to Plasma Thrusters," Engineer's Thesis, Naval Postgraduate School, June 1997.

Smith, T.R., "Thermal Analysis of PANSAT," Master's Thesis, Naval Postgraduate School, December 1997.

DoD KEY TECHNOLOGY AREA: Other (Propulsion and Energy Conversion)

KEYWORDS: Magnetoplasma-Dynamic (MPD), Electric Propulsion, Thermal Analysis, Spacecraft Thermal Control

A FUNDAMENTAL STUDY OF COMPRESSIBILITY EFFECTS ON DYNAMIC STALL OF FIXED AND ADAPTIVE AIRFOILS

M.S. Chandrasekhara, Research Professor
M.F. Platzer, Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To understand the fundamental fluid flow physics of compressible unsteady flow separation and dynamic stall onset over fixed and variable geometry airfoils, leading to innovative flow control methods.

SUMMARY: The research resulted in the identification of some of the key mechanisms of compressible dynamic stall onset. These are laminar separation bubble bursting, shock-induced flow separation, and interaction of the bubble with the local supersonic flow. Primarily, all are attributable to the development of strong adverse pressure gradient over the airfoil, which needs to be mitigated for achieving flow control. This led to the concept of the Dynamically Deforming Leading Edge (DDLE) airfoil, whose leading edge curvature can be changed by as much as 320% in real-time while the airfoil oscillates, providing an airfoil that can adapt to each flow condition instantaneously. Successful preliminary tests were conducted to establish the proof-of-concept.

PUBLICATION:

Chandrasekhara, M.S., "A Fundamental Study of Compressibility Effects on Dynamic Stall of Fixed and Adaptive Airfoils," Final Report submitted to Army Research Office, September 1997.

CONFERENCE PRESENTATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Control of Flow Separation Using Adaptive Airfoils," AIAA 36th Aerospace Sciences Meeting, Reno, NV, January 1997.

Chandrasekhara, M.S., Carr, L.W., and Wilder, M.C., "Development of High Speed Imaging and Analysis Techniques for Compressible Dynamic Stall," AGARD 81st Meeting and Symposium, Seattle, WA, September 1997.

THESIS DIRECTED:

Van Dyken, R.D., "Experimental and Computational Analysis of Separation Bubbles for Compressible Steady and Oscillatory Flows Over a NACA 0012 Airfoil at $M\infty = 0.3$ and Re = 540,000," Doctor of Philosophy Dissertation, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Helicopter Blade Stall, Unsteady Aerodynamics, Shock/Boundary Layer Interactions

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To develop flow control schemes through management of the unsteady vorticity field by dynamically deforming an airfoil for prevention of flow separation.

SUMMARY: This research project initiated in April 1997 is aimed at establishing the fluid mechanics of the flow over a dynamically deforming leading edge (DDLE) airfoil under high loading conditions as it operates near stall. Preliminary studies have shown that it is possible to reattach even grossly separated flow by changing the DDLE airfoil leading edge curvature and to re-establish the vorticity field for producing lift at angles well above the maximum operating angles of attack of a fixed geometry airfoil. In view of its relevance to helicopter retreating blade stall alleviation, an oscillating airfoil will be dynamically deformed carefully as it pitches up.

PUBLICATION:

Chandrasekhara, M.S., Carr, L.W., Wilder, M.C., Paulson, G.N., and Sticht, C.D., "Design and Development of a Dynamically Deforming Leading Edge Airfoil for Unsteady Flow Control," *IEEE Publication 97CH36121,* September 1997.

CONFERENCE PRESENTATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Unsteady Stall Control Using Dynamically Deforming Airfoils," AIAA 15th Applied Aerodynamics Conference, Atlanta, GA, June 1997.

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Fluid Mechanics of Wing Adaptation for Separation Control," 7th Asian Congress of Fluid Mechanics, Madras, India, December 1997.

Geissler, W., Chandrasekhara, M.S., Platzer, M.F., and Carr, L.W., "The Effect of Transition Modeling on the Prediction of Deep Dynamic Stall," 7th Asian Congress of Fluid Mechanics, Madras, India, December 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Flow Control, Helicopter Blade Stall, Smart Materials, Deforming Airfoils

RESEARCH ON AUTONOMOUS AIR VEHICLES

Russell W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: To investigate autonomous operation of fixed and rotary wing aircraft.

SUMMARY: Work has been performed to develop a small autonomous rotary-wing vehicle. The vehicle and a subset of the eventual avionics suite have been purchased and integration of the avionics suite has begun. The vehicle will carry a sensor suite including inertial, GPS, vision and ultrasonic sensors. Data from these sensors is transmitted to a ground-based control station where the processing and autonomous control functions reside. Control signals are transmitted from the ground station to the air vehicle. The vehicle will support research into autonomous control, vision-based navigation, and the use of passive sensors to land VTOL aircraft on ships.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Electronics, Modeling and Simulation, Sensors

KEYWORDS: Autonomous Vehicles, Unmanned Air Vehicles (UAV), Avionics, Robotics

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TURBINE TIP-LEAKAGE FLOWS

G. V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsors: Naval Air Warfare Center-Aircraft Division and Naval Postgraduate School

OBJECTIVE: This project entails non-intrusive, laser-Doppler-velocimetry (LDV) measurements, in the endwall region of a turbine. The objective of the project is to transfer the measurement technique developed on an annular turbine cascade to an operational turbine test article.

SUMMARY: The measurement technique was presented at the 33rd Joint Propulsion Conference in Seattle. The specific turbine test article is the turbine of the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME) and the particular hardware was designed and manufactured by Pratt & Whitney for NASA.

The project during 1996-1997 consisted of the upgrade to the water cooling system of the HPFTP so that longer run times could be achieved. This entailed the commissioning of the new closed loop water cooling system on the dynamometer. The next task was to perform LDV measurements in the rotor of the turbine for the HPFTP. The first task was successfully completed and the turbine has run continuously for extended periods of time with no recirculating water problems. The turbine was also moved closer to the sidewall of the test cell to accommodate the standard optics LDV system. The move entailed lengthening the inlet piping to the turbine. A picture of the new arrangement can be viewed at the Turbopropulsion Laboratory homepage (http://www.aa.nps.navy. mil/~garth/HPFTP3.gif). The second task was initiated with the successful installation of the LDV in the test cell. Continuous LDV measurements have been over the turbine rotor in its tip region.

CONFERENCE PRESENTATION:

Hobson, G. V., Donovan, W. H., and Spitz, J. D., "LDV Measurements in the Endwall Region of an Annular Turbine Cascade Through an Aerodynamic Window," AIAA 97-3012, 33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Seattle, WA, July 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Turbine, Laser, Velocimetry, Tip-Leakage Flows

FAN AND COMPRESSOR STALL

G. V. Hobson, Associate Professor
R. P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: This is a continuing project to validate off-design and stall prediction for controlled-diffusion (CD) blading experimentally, and thereby enable the development of higher blade-loading designs.

SUMMARY: Two and three component laser-Doppler velocimetry, pressure probe, laser sheet and surface-flow visualization techniques have been applied to obtain measurements of the flow through first and second generation CD blading in a 60x10 inch rectilinear cascade wind tunnel. Second generation blading, having approximately half the solidity of the first-generation design, when operated at high incidence angles, gave rise to laminar separation bubbles at lower Reynolds numbers and trailing-edge separation at higher Reynolds numbers. Significant three-dimensional effects were found that required attention experimentally to ensure span-wise symmetry. Analytically, a three-dimensional CFD study was initiated to assess predictive capability at higher Reynolds numbers.

PUBLICATIONS:

Hobson, G.V., Chapter 17; "Laser-Doppler Velocimetry and Flow Visualization of Flow Through a Controlled-Diffusion Compressor Cascade at Stall," *Advances in Turbomachinery Fluid Dynamics and Heat Transfer,* Marcel Dekker, 1996.

Hobson, G.V. and Dober, D.M., "Three-Dimensional Fiber-Optics LDV Measurements in the Endwall Region of a Linear Cascade of Controlled-Diffusion Stator Blades," *International Journal of Turbo and Jet Engines*, Vol.14, No.1, 1997.

CONFERENCE PRESENTATIONS:

Hobson, G.V., Schnorenberg, D.G. and Grove, D.V., "Effect of Reynolds Number on Laminar Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," accepted for presentation at the ASME Turbo Expo '98-Land, Sea, & Air-43rd Gas Turbine & Aeroengine Congress, Users' Symposium, and Exposition, Stockholm, Sweden, 2-5 June 1998.

Hobson, G.V., Ganaim Rickel, H.J., and Williams, A.J.H., "Laser-Doppler Velocimetry and Flow Visualization of Flow Through a Compressor Cascade at Stall," ASME Paper 96-GT-484, 41 ASME International Gas Turbine and Aeroengine Congress, Exposition and Users Symposium, Birmingham, UK, 10-13 June 1996, (accepted for publication in the *Journal of Turbomachinery*).

THESES DIRECTED:

Carson, S.W., "The Computational Fluid Dynamic Description of Stall in a Cascade of Controlled-Diffusion Compressor Blades," Master's Thesis, Naval Postgraduate School, September 1997.

Grove, D.V., "Experimental and Numerical Investigation of Second-Generation Controlled-Diffusion Compressor Blades in Cascade," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Controlled-Diffusion Blading, LDV Measurements, Compressor Cascade Stall

DEPLOYMENT OF THE APEX AIRCRAFT AT HIGH ALTITUDE

Richard M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Dryden Flight Research Center

OBJECTIVE: To assist a design team in the development of a remotely-piloted aircraft to be dropped from 100,000 feet for aerodynamic experimentation.

SUMMARY: The meteorological need for atmospheric data at high altitudes requires basic data for the design of efficient aircraft able to loiter for extended periods in this extreme environment. The Apex Program is producing a high-altitude testbed aircraft to achieve trimmed flight at altitudes of over 100,000 feet to conduct aerodynamic experiments. The work this year consisted of conducting a final tail design, designing and wind-tunnel testing a wind vane for good response at the high altitude, analyzing the pressure lags in a potential air-data boom, and developing a 1/3-scale radio-controlled sailplane and performing flight simulation of it during the pullout maneuver to model the Apex launch. This is a continuing project.

OTHER: A technical report summarizing the wind-tunnel tests and pressure-lag analysis is in progress.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Environmental Quality, Sensors, Modeling and Simulation

KEYWORDS: Airdata, Aerodynamics, Flight Mechanics

UNMANNED AIR VEHICLE TECHNOLOGY DEVELOPMENT

Richard M. Howard, Associate Professor
R.P. Shreeve, Professor
G.V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Defense Airborne Reconnaissance Office

OBJECTIVE: To support future unmanned air vehicle (UAV) development with studies of the potential performance of alternate engines for application in Predator and Global Hawk classes of UAVs, of bus architectures for a common UAV architecture, and of improved airframe aerodynamics through modeling and simulation.

SUMMARY: A panel computer program was used to model the Predator Unmanned Aerial Vehicle at its trim flight condition. An analysis was begun to study how future external modifications might impact range and endurance. In avionics, a proof-of-concept cell-phone architecture was developed as a commercial-off-the-shelf (COTS) approach to a common bus architecture for future UAVs. In propulsion, reconnaissance missions require relatively low power and/or high altitudes. Current reciprocating engines do not have the reliability of gas turbines and can not use heavy fuel. Analytical studies examined the potential impact of gas turbine engine variants on reconnaissance vehicles with emphasis on the recuperated gas turbine cycle. An experimental study sought to establish performance characteristics of small gas turbines operating with jet propulsion fuel. This is a continuing program.

OTHER: A report was provided to the Defense Airborne Reconnaissance Office by Dr. Jim Hauser under contract to NPS for the avionics study.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles, Computing and Software, Sensors, Modeling and Simulation

KEYWORDS: UAV, Avionics Architecture, Aerodynamics, UAV Propulsion, Small Gas Turbine Engines, Recuperated Turbofans

ADVANCED AVIONICS TECHNOLOGY

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform research and development in advanced avionics technology topics relevant to the Naval Air Systems Command (NAVAIR) Maritime Avionics Subsystems and Technology (MAST) program.

SUMMARY: Over the past several years, under NAVAIR sponsorship, NPS has embarked on the development and evaluation of GPS/INS integration systems. In particular, progress has been made in the development of the uniform framework for the INS/GPS integration using Kalman Filtering. The work is ongoing and strives to unify various approaches to the development of INS systems and their integration with GPS using Kalman Filtering.

PUBLICATIONS:

Kaminer, I., Pascoal, A.M., Hallberg, E., and Silvestre, C., "Trajectory Tracking for Autonomous Vehicles: An Integrated Approach to Guidance and Control," *Proceedings of 1997 AIAA Conference on Guidance, Navigation and Control,* pp. 1133-1138, New Orleans, LA, 1997.

Kaminer, I., Pascoal, A.M., Hallberg, E., and Silvestre, C., "Trajectory Tracking for Autonomous Vehicles: An Integrated Approach to Guidance and Control," to appear in *AIAA Journal of Guidance, Control and Dynamics*, January/February 1998.

THESES DIRECTED:

Allen, P., "Incorporation of a Differential GPS in the Control of an Unmanned Aerial Vehicle for Precise Navigation in the Local Tangent Plane," Master's Thesis, Naval Postgraduate School, March 1997.

Hallberg, E., "On Integrated Plant, Control and Guidance Design," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1997.

Papageorgiou, E.C., "Development of a Dynamic Model for a UAV," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Avionics)

KEYWORDS: GPS, Inertial Navigation, Kalman Filtering, Rapid Prototyping

JOINT STAND-OFF WEAPON (JSOW) UNITARY CAPTIVE AIR TRAINING MISSILE (CATM) CONCEPTUAL DESIGN

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform conceptual design studies on a captive air training missile for the JSOW Unitary Missile and to explore the possibility of extending its applicability to other missiles.

SUMMARY: This project was responsible for the issues related to the JSOW CATM avionics system and for the development of cockpit steering commands requirements for the carriage aircraft. The work accomplished includes development of the preliminary functional requirements for JSOW CATM avionics as well as development of JSOW 6DOF nonlinear simulation and guidance and control system for a typical JSOW profile.

THESIS DIRECTED:

Sardana, V., "Incorporation of Joint Standoff Weapon Steering Commands with Carriage Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Stand-off Weapons, Avionics)

KEYWORDS: JSOW CATM, Avionics, Guidance and Control

CLOSED-LOOP PITCH CONTROL EFFECTOR SIZING

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Langley Research Center

OBJECTIVE: This project developed a new optimization tool for obtaining the closed loop tail sizing criteria for high-speed civil transport (HSCT).

SUMMARY: In particular, the tool is capable of determining the maximum cg travel for a given HSCT tail volume subject to a variety of disturbance recovery and closed loop constraints as well as structural mode considerations. The disturbances considered included vertical gust and sinusoidal inputs. The closed loop constraints included the effect of feedback specifications, such as MIL STD 1797 Level I and II flying qualities requirements. Furthermore, the HSCT actuator amplitude and rate constraints were accounted for. Moreover, the tool has the option of including the structural mode considerations.

PUBLICATIONS:

Berglund, E. and Kaminer, I., "An Integrated Approach to Plant Optimization and Controller Design," *Preprints Robust Control Design, 2nd IFAC Symposium*, pp. 235-240, Budapest, Hungary, 25-27 June 1997.

Kaminer, I. and Hallberg, E., "Closed Loop Pitch Control Effector Sizing," National Aeronautics and Space Administration Contractor Report, 1997

Kaminer, I., Howard, R. M., and Buttrill, C., "Development of Closed-Loop Tail-Sizing Criteria for a High Speed Civil Transport," *Journal of Aircraft*, Vol. 34, No. 5, pp. 658-664, September-October 1997.

THESIS DIRECTED:

Hallberg, E., "On Integrated Plant, Control and Guidance Design," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Other (Avionics)

KEYWORDS: Closed-Loop Pitch Control

PASSIVE SENSOR-BASED CONTROL OF NONLINEAR AUTONOMOUS SYSTEMS

I.I. Kaminer, Assistant Professor
R.W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this proposal was to investigate sensor fusion architectures and mathematical algorithms required to support autonomous vertical take off and landing (VTOL) of uninhabited combat air vehicles on ships using passive sensors.

SUMMARY: Preliminary results were obtained on the synthesis of time-varying and nonlinear filters that integrate vision, GPS and inertial sensors to provide an accurate estimate of ship's position with respect to the aircraft as well as of the ship's inertial velocity.

DoD KEY TECHNOLOGY AREA: Sensors, Other (Avionics)

KEYWORDS: Non-Linear Autonomous Systems, VTOL

FY97 ENGINEERING AND TECHNICAL SUPPORT FOR THE UNMANNED AIR VEHICLE (UAV) JOINT PROGRAM OFFICE (JPO) PHASE II CONTRACT EFFORT

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Unmanned Air Vehicle Joint Program Office

OBJECTIVE: Provide engineering and technical support to UAV JPO in managing the Phase II of the SBIR proposal, "Low-Cost Fault Tolerant Controls for Unmanned Air Vehicles."

SUMMARY: The project was kicked off at Naval Postgraduate School in November 1997.

DoD KEY TECHNOLOGY AREA: Other (Unmanned Air Vehicles)

KEYWORDS: Unmanned Air Vehicles, UAV

JOINT STAND-OFF WEAPON (JSOW) UNITARY CAPTIVE AIR TRAINING MISSILE (CATM) DESIGN STUDIES

Gerald Lindsey, Professor
Oscar Biblarz, Professor
I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
David Jenn, Associate Professor
Department of Electrical and Computer Engineering
Sponsors: Naval Air Systems Command and Naval Postgraduate School

OBJECTIVE: To perform advanced conceptual design studies on the JSOW Captive Air Training Missile (CATM) in preparation for preliminary design and construction of the CATM by Raytheon Texas Instruments.

SUMMARY: Studies were conducted in six areas: (1) structural weight and gross weight estimation; (2) structural strength analysis and fatigue life estimates; (3) airframe configurations for drag minimization; (4) CATM flight control studies to determine pilot cues for flying the captive carrier aircraft during training flights; (5) restrictions on communications be-

tween controlling and carrying aircraft due to captive position of the CATM; and (6) logistical studies of inventory required and projected usage of the CATM in the fleet.

PUBLICATION:

Pomerantz, B. and Biblarz, O., "CFD Verification of Transonic Area and Similarity Rules with Missile Configurations," *Proceedings of the 37th Israel Annual Conference on Aerospace Sciences*, Israel, February 1997.

CONFERENCE PRESENTATION:

Pomerantz, B. and Biblarz, O., "CFD Verification of Transonic Area and Similarity Rules with Missile Configurations," 37th Israel Annual Conference on Aerospace Sciences, Tel-Aviv/Haifa, Israel, February 1997.

THESES DIRECTED:

Pomerantz, B., "Aerodynamic Analysis of a Modified Pylon-Mounted JSOW CATM Using Multi-Grid CFD Methods," Master's Thesis, Naval Postgraduate School, March 1997.

Sardana, V., "Incorporation of Joint Standoff Weapon Steering Commands with Carriage Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Missile, Missile Design, CATM, JSOW, Pilot Training

PLUME AFTERBURNING SUPPRESSION USING MIXING CONTROL AND COMBUSTION REQUIREMENTS FOR PULSE-DETONATION ENGINES

D.W. Netzer, Distinguished Professor
C.M. Brophy, National Research Council Post-Doctoral Research Associate
Department of Aeronautics and Astronautics
Sponsors: Office of Naval Research and the Naval Postgraduate School

OBJECTIVE: (1) To determine the effects of solid propellant rocket motor exhaust particulates and nozzle geometry on the suppression of plume afterburning and to obtain effective nozzle geometries which do not adversely effect thrust. (2) To experimentally determine the combustion requirements for sustainment of full-strength detonations and the detonation characteristics in liquid-fueled, pulse-detonation engines.

SUMMARY: A combined investigation was conducted with another research project at NPS in order to measure the effects of propellant composition and nozzle geometry on the exhaust plume signature from the UV to millimeter wavelengths. Both highly metallized and minimum smoke propellants were used with nozzles that had various expansion ratios and geometries to increase plume mixing with the ambient air. A detonation tube was designed, constructed, and utilized with gaseous fuel-air mixtures. An acrylic model was utilized to examine various liquid fuel injection methods and to determine the spatial and temporal variations of the liquid droplet size distribution. Air assist atomizers were found to produce a wide range of droplet sizes, with the largest droplets penetrating further into the tube. For radial injection these large droplets impinge on the opposing wall and for axial injection they result in highly non-uniform fuel distribution. The initial data indicated that the probable solution rests in the generation of very small droplets that can be injected with the purge air.

PUBLICATIONS:

Ruttenberg, E.C. and Netzer, D.W., "Aluminum Particle Breakup in Combustion Environments," to appear in *Journal of Propulsion and Power.*

Hill, J.A., Ruttenberg, E.C., and Netzer, D.W., "Spatial Variations in Aluminum Oxide and Zirconium Oxide Particle Sizes in Rocket Motors and Plumes," *Proceedings of the l997 JANNAF Exhaust Plume Technology Subcommittee Meeting,* CPIA Pub. 656, Vol. I, pp. 229-240, May l997.

CONFERENCE PRESENTATIONS:

Beals, K.A., Brophy, C.M., Fadler, D.C., and Netzer, D.W., "Plume Afterburning Suppression Using Mixing Control and Combustion Requirements for Liquid-Fueled, Pulse-Detonation Engines," 10th ONR Propulsion Meeting, Monterey, CA, October 1997.

Brophy, C.M. and Netzer, D.W., "Pulse-Detonation Engine Investigations at the Naval Postgraduate School," ONR/NPS Pulse-Detonation Engine (PDE) Workshop, Monterey, CA, 10 October l997.

THESIS DIRECTED:

Beals, K.A., "Foundation of a Long-Term Research Effort in Liquid-Spray Detonations for Use in a Pulse-Detonation Engine," Engineer's Thesis, Naval Postgraduate School, June l997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Rocket Plumes, Afterburning, Detonations

RISK ANALYSIS OF MISSION NEED STATEMENT FOR TACTICAL HIGH-SPEED STRIKE CAPABILITY

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Accurate Automation Corporation

OBJECTIVE: Accurate Automation Corporation has developed and is currently test flying LoFlyte, a subscale model of a hypersonic, waveriding aircraft. The Naval Postgraduate School has undertaken this Cooperative Research and Development Agreement (CRADA) to assess risks and technologies associated with transitioning the LoFlyte concept to the mission need for a tactical high-speed strike capability in the hypersonic realm.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Risk Analysis

CIVILIAN-MILITARY ENVIRONMENTAL INTERFACE ISSUES AND THEIR IMPACT ON NATIONAL SECURITY

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: Research was conducted to further define issues in environmental security. A case study has been initiated regarding the remediation of the Fort Ord rifle ranges prior to their conversion to parkland. Funding sources are being sought to fund the case study. Funding sources are also being sought for environmental security research. One summary paper was prepared during 1997 to characterize environmental security research conducted to date.

PUBLICATION:

Newberry, C.F. and Grubbs, J.H., "Environmental Security: The Response to Environmental Threats to Societies," *Proceedings of the 1997 ASEE Annual Meeting and Exposition*, Milwaukee, WI, 15-18 June 1997.

CONFERENCE PRESENTATION:

Newberry, C.F. and Grubbs, J.H., "Environmental Security: The Response to Environmental Threats to Societies," 1997 ASEE Annual Meeting and Exposition, Milwaukee, WI 15-18 June 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Environmental Quality Security, Fort Ord

OSCILLATORY AIRFOIL AERODYNAMICS

M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: To perform computational and experimental investigations of the unsteady separated flow phenomena on airfoils, of the flow control potential due to airfoil flapping, and of the flutter and gust response characteristics of airfoils, helicopter and turbomachinery blades.

SUMMARY: Water and wind tunnel experiments were performed to study the flow over double-delta wings at high incidence angles, the characteristics of separation bubbles on NACA 0012 airfoils, the influence of pressure gradients on the flow over cavities, and the ability of flapping airfoils to control flow separation. Also, boundary layer and Navier-Stokes calculations were performed to predict these flow phenomena.

PUBLICATION:

Hebbar, S.K., Platzer, M.F., and Chang, W.H., "Control of High-Incidence Flow on Double-Delta Wings Undergoing Sideslip," *Journal of Aircraft*, Vol. 34, No. 4, pp. 506-513, July-August 1997.

CONFERENCE PRESENTATIONS:

Fritzelas, A., Platzer, M.F., and Hebbar, S.K., "The Influence of Reynolds Number on the High-Incidence Flow Over Double-Delta Wings," AIAA Paper 97-0046, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

Jones, K.D. and Platzer, M.F., "A Fast Method for the Prediction of Dynamic Stall Onset on Turbomachinery Blades," ASME Paper 97-GT-453, International Gas Turbine Congress, Orlando, FL, 2-5 June 1997.

Lai, J.C.S., Yue, J.W., and Platzer, M.F., "Control of Backward-Facing Step Flow Using a Flapping Airfoil," ASME Fluids Engineering Division Summer Meeting, Vancouver, Canada, 22-26 June 1997.

Margason, R.J. and Platzer, M.F., "Effect of Two-Dimensional Cavities on Boundary Layers in Adverse Pressure Gradients," AIAA Paper 97-0300, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

THESIS DIRECTED:

Van Dyken, R.D., "Experimental and Computational Analysis of Separation Bubble Behavior for Compressible, Steady and Oscillatory Flows over a NACA 0012 Airfoil," Doctor of Philosophy Dissertation, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Aerodynamics, Separated Flows, Aeroelasticity, Flow Control, Oscillatory Flows

DEVELOPMENT OF AN ADVANCED MISSILE AERODYNAMIC PREDICTION METHOD

M.F. Platzer, Distinguished Professor
I.H. Tuncer, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: To develop Navier-Stokes and panel code solutions for the vortical flow over complete missile configurations in steady or maneuvering high angle of attack flight.

SUMMARY: Navier-Stokes computations were completed for subsonic flow over a complete missile configuration, including the flow into a missile engine through a flush-mounted engine inlet, using the NASA-Ames OVERFLOW code. Also, the NASA-Ames panel code PMARC was extended to compute the flow over bodies of revolution at high angle of attack.

CONFERENCE PRESENTATIONS:

Geissler, W., Platzer, M.F., Chandrasekhara, M.S., and Carr, L.W., "The Effect of Transition Modeling on the Prediction of Compressible Deep Dynamic Stall," 7th Asian Congress of Fluid Mechanics, Madras, India, 8-12 December 1997.

Platzer, M.F. and Tuncer, I.H., "Navier-Stokes Computation of High-Incidence Missile Flows," Air Force/Navy/Army Workshop on High-Angle-of-Attack Missile Aerodynamics, Eglin Air Force Base, FL, 14-17 October 1997.

Tuncer, I.H., van Dyken, R.D., and Platzer, M.F., "A Computational Study of Subsonic Flowfields over a Missile Configuration" AIAA Paper 97-0635, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

Tuncer, I.H. and Platzer, M.F., "PMARC Potential Flow Solutions with Wakes over an Ogive Cylinder at High Incidence," AIAA Paper 97-1968, 28th AIAA Fluid Dynamics Conference, Snowmass Village, CO, 29 June-2 July 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Missile Aerodynamics, Vortical Flows, Computational, Fluid Dynamics

DEVELOPMENT OF SMALL UNMANNED AIR VEHICLES

M.F. Platzer, Distinguished Professor
K.D. Jones, Research Assistant Professor
I.H. Tuncer, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Research Laboratory

OBJECTIVE: The objective of the proposed effort is the exploration and demonstration of flapping wing propulsion for small unmanned air vehicles

SUMMARY: Computations were completed to predict the thrust of flapping/pitching airfoils and airfoil combinations as a function of frequency and amplitude of oscillation and as a function of the phase angle between flapping and pitching. Also, a wind tunnel model was designed and built to measure the thrust as a function of these parameters and a first set of measurements was completed.

CONFERENCE PRESENTATIONS:

Jones, K.D. and Platzer, M.F., "Numerical Computation of Flapping Wing Propulsion and Power Extraction," AIAA paper 97-0826, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

Tuncer, I.H., Lai, J.C.S., Ortiz, M., and Platzer, M.F., "Unsteady Aerodynamics of Stationary/Flapping Airfoil Combination in Tandem," AIAA paper 97-0659, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

THESIS DIRECTED:

Pollard, S.J., "Evaluation of the CMARC Panel Code Software Suite for the Development of a UAV Aerodynamic Model," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Hydrodynamics)

KEYWORDS: Unsteady Aerodynamics, Unmanned Air Vehicles, Flapping Wing Propulsion

ADVANCED MULTIDISCIPLINARY ANALYSIS AND DESIGN OPTIMIZATION METHODS FOR SUBSONIC TRANSPORT AIRCRAFT

M.F. Platzer, Distinguished Professor
K.D. Jones, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsors: McDonnell-Douglas Aircraft Company and Naval Postgraduate School

OBJECTIVE: To contribute to the development of advanced multidisciplinary analysis and design optimization methods for subsonic transport aircraft.

SUMMARY: This work entails the use/extension of three-dimensional computational fluid dynamics codes for viscous subsonic/transonic flow over a wing/body/nacelle/pylon configuration and the development of new turbulence models. Also, it involves the use of a finite element code to determine the aircraft deformation under loading and to speed up the computations by means of parallelization.

CONFERENCE PRESENTATIONS:
Jones, K.D. and Platzer, M.F., "On the Prediction of Dynamic Stall on Airfoils in Low Speed Flow," 8th International Symposium on Unsteady Aerodynamics and Aeroelasticity of Turbomachines, Stockholm, Sweden, 14-18 September 1997.

Sanz, W. and Platzer, M.F., "On the Calculation of Laminar Separation Bubbles Using Different Transition Models," ASME Paper 97-GT-453, International Gas Turbine Congress, Orlando, FL, 2-5 June 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Structures)

KEYWORDS: Aerodynamics, Computational Fluid Dynamics, Structures, Finite Element Modeling, Design Optimization

LAUNCH PERIOD ANALYSIS FOR PLUTO EXPRESS

I. M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory

OBJECTIVE: This was a small exploratory research project with the objective to perform a detailed analysis of the Jupiter Gravity Assist (JGA) trajectories for the Pluto Express spacecraft, now renamed the Pluto-Kuiper Express.

SUMMARY: The Jet Propulsion Laboratory (JPL) is designing a space mission that will conduct, for the first time, a reconnaissance of the Pluto/Charon system to determine their composition, atmosphere and geological characteristics among other things. The spacecraft will also be sent to the Kuiper Belt that is at the edge of the solar system. Using the JPL software MIDAS and CATO, an analysis was performed for two nominal launch period opportunities that occur in November 2003 and December 2004. Most of the analysis was performed by Michelle Reyes as part of her thesis required for the Master of Science degree in Astronautical Engineering. The results allow JPL to make the final decision for the most feasible arrangement for launch. Initially, the JGA was supposed to have been a "back-up" plan for the trajectory design. JPL is seriously considering the JGA as the baseline trajectory. Due to the success of this project, JPL has an ongoing partnership with NPS on the Advanced Mars Mission Project.

CONFERENCE PRESENTATION:

Reyes, M.D., Matousek, S.E., and Ross, I.M., "Launch Period Analysis for the Jupiter Gravity Assist Opportunities to Pluto," to be presented at the 8th AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, 9-11 February 1998.

THESIS DIRECTED:

Reyes, Michelle D., "Launch Period Analysis for the Jupiter Gravity Assist Opportunities to Pluto," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Pluto/Charon, Kuiper Belt, Jupiter Gravity Assist Trajectories

APPLICATION OF PERIODIC OPTIMAL CONTROL TO SPACE MANEUVERS

I. M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this proposal was to develop a non-linear, fuel-optimal guidance algorithm by analyzing the necessary conditions of optimality for periodic stationkeeping of low-Earth-orbiting satellites. This was a collaborative proposal with Professor Fahroo of the Department of Mathematics.

SUMMARY: In the course of investigating the extremal solutions to the problem, a new type of orbital transfer was discovered. Collaborative work with Professor Fahroo has resulted in advancing an algorithm to solve the optimization problem. The algorithm is based on a new spectral collocation method. The results show that the often-used Hohmann transfer is not the optimal maneuver for orbit maintenance. Further analysis performed by LT Karl Jensen has shown that it is will be possible to devise stationkeeping maneuvers that are fuel-optimal. These results could potentially change the orbit maintenance operations of future low-Earth-orbiting satellites. The intention is to use these results to sell the research to potential sponsors such as the National Aeronautics and Space Administration and Naval Reconnaissance Office.

PUBLICATION:

Ross, I. M., "Suboptimal Singular Orbital Transfer," *Journal of Guidance, Control, and Dynamics*, Vol. 20, No.3, pp. 605-607, May-June 1997.

CONFERENCE PRESENTATIONS:

Jensen, K. E., Fahroo, F., and Ross, I. M., "Application of Periodic Optimal Control Theory to the Orbit Reboost Problem," to be presented at the 8th AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, 9-11 February 1998.

Fahroo, F. and Ross, I. M., "A Spectral Collocation Method for Solving Optimal Periodic Control Problems," to be presented at the AIAA Guidance, Navigation and Control Conference, Boston, MA, 10-12 August 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Orbit Maintenance, Low-Earth-Orbiting Satellites

HIGH CYCLE FATIGUE (HCF)/SPIN TEST RESEARCH

R.P. Shreeve, Professor
G.V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: To reactivate the Spin-Pit Facility at the Turbopropulsion Laboratory (TPL) and conduct a program to develop blade excitation and measurement techniques to be used on the Navy's Rotor Spin Facility at the Naval Air Warfare Center-Aircraft Division (NAWCAD).

SUMMARY: This is a new project. The National High Cycle Fatigue (HCF) Initiative has identified a potentially important role for spin testing in the development cycle of new engines, and in eliminating HCF problems in existing engines. Several blade-excitation techniques have been proposed for use in vacuum pits but no satisfactory system has yet been proven. The Spin-Pit Facility at TPL is a production-sized pit in which blade excitation techniques will be evaluated and demonstrated, eventually at full scale. Once proven, the system will be installed on the Navy's production pits at NAWCAD. Close collaboration between NPS and NAWCAD will be maintained. In addition, other research projects to support the Navy's participation in the HCF initiative will be explored.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Spin Testing, High Cycle Fatigue, Blade Excitation

TRANSONIC FAN DESIGN AND VALIDATION

R. P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: This is a continuing project to advance aircraft engine fan technology. Experimentally, the goal is to install a new stage, designed by N. Sanger at NASA using CFD methods, in the transonic compressor test rig, and to evaluate all aspects of the performance using advanced measurement techniques. Code versus measurement comparisons will be documented, and the test facility and instrumentation will be proven for use in the evaluation of innovative designs. Analytically, the goal is to develop a new geometry package suitable for use in designing blading to incorporate sweep.

SUMMARY: A prototype transonic fan stage was installed and a first set of stage performance-map measurements were obtained to 80% of design speed. Code calculations showed good agreement. The stage was remanufactured following failure of the spinner attachment, and a refined fillet design was incorporated. The development of the pressure sensitive paint (PSP) measurement technique to map the rotor surface pressure was continued using a separate turbine-driven test rig. The development of a new geometry package to allow rotor design to incorporate sweep, and eventually allow aero-structural-manufacturing optimization, was successfully demonstrated using the NASA rotor as a baseline.

PUBLICATION:

Abdelhamid, H.F. and Shreeve, R.P., "Three-Dimensional Geometry Package for Axial Compressor Blading; Initial Code Listing," Naval Postgraduate School Technical Report, NPS-AA-97-001, September 1997.

CONFERENCE PRESENTATIONS:

Abdelhamid, H.F. and Shreeve, R.P., "Sweep in a Transonic Fan Design: Part 1. 3D Geometry Representation," submitted for presentation at the ASME Turbo Expo '98-Land, Sea, & Air-43rd Gas Turbine and Aeroengine Congress, Users' Symposium and Exposition, Stockholm, Sweden, 2-5 June 1998.

Abdelhamid, H.F., Shreeve, R.P., and Hobson, G.V., "Sweep in a Transonic Fan Design: Part 2. Flow and Stress Analyses," submitted for presentation at the ASME Turbo Expo '98-Land, Sea, & Air-43rd Gas Turbine and Aeroengine Congress, Users' Symposium and Exposition, Stockholm, Sweden, 2-5 June 1998.

Seivwright, D.L. and Shreeve, R.P., "Flat Plate in a Highly-Underexpanded Sonic Jet," AIAA 97-0066, AIAA 35th. Aerospace Sciences Meeting and Exhibit, Reno, NV, 15-18 January 1997.

THESES DIRECTED:

Abdelhamid, H.F., "Incorporation of Sweep in a Transonic Fan Design Using a 3D Blade-Row Geometry Package Intended for Aero-Structural-Manufacturing Optimization," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1997.

Gahagan, S.G., "Pressure-Sensitive Paint Measurement on Rotor Blading," Master's Thesis, Naval Postgraduate School, March 1997.

Grossman, B.L., "Testing and Analysis of a Transonic Axial Compressor," Master's Thesis, Naval Postgraduate School, September 1997.

Quinn, K.J., "Pressure-Sensitive Paint Measurement Technique Development for Turbomachinery Application," Engineer's Thesis, Naval Postgraduate School, December 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Transonic Compressor Design and Test, Pressure-Sensitive Paint, Swept Fan Geometry Package

UNMANNED AIR VEHICLE (UAV) PROPULSION TECHNOLOGY

R. P. Shreeve, Professor
G. V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Defense Airborne Reconnaissance Office

OBJECTIVE: To examine the potential performance of alternate engines for application in Predator and Global Hawk classes of UAVs.

SUMMARY: Reconnaissance missions require relatively low power and/or high altitudes. Current reciprocating engines do not have the reliability of gas turbines and cannot use heavy fuel. Analytical studies examine the potential impact of gas turbine engine variants on reconnaissance vehicles with emphasis on the recuperated gas turbine cycle. An experimental study seeks to establish performance characteristics of small gas turbines operating with JP fuel.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: UAV Propulsion, Small Gas Turbine Engines, Recuperated Turbofans

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMANCHE HELICOPTER

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Donald A. Danielson, Professor
Department of Mathematics
Joshua H. Gordis, Associate Professor
Department of Mechanical Engineering
Sponsor: U. S. Army Aviation and Troop Command-Comanche Program Manager's Office

OBJECTIVE: For Professors Wood, Danielson, and Gordis to continue their work in support of the ongoing development of the Army's RAH-66 Comanche helicopter. Tasks include vibration and structural dynamics analysis and correlation of calculated results with results of ground vibration tests. It is important that NPS maintain a "current" dynamic NASTRAN model of the Comanche. A current model permits NPS to respond quickly to requests from the Program Manager's Office to carry out parametric investigations of RAH-66 vibrations in cooperation with the Army and Sikorsky in which NPS results can be quickly compared to those of other principals and applied to the aircraft if desired.

SUMMARY: Described is a summary of engineering work conducted at the Naval Postgraduate School in 1997 for the Comanche Program Manager's Office, in support of the Army-Boeing-Sikorsky RAH-66 Comanche Helicopter Program. The prototype helicopter is currently undergoing flight test envelope expansion at Sikorsky Aircraft's Flight Test Facility at West Palm Beach, FL.

The RAH-66 Comanche's stealth design requires the use of radar absorbing material (RAM) on the outer skin of the aircraft. The reduced stiffness properties of RAM produce insufficient tail torsional stiffness, necessitating the use of non-radar absorbing graphite on the outer skin of the prototype's tail section. An investigation was carried out to determine the structural design modifications required to increase the tailcone's stiffness to allow the use of RAM on the outer skin and still meet all structural requirements. The reference or baseline case is a finite element model that was constructed to represent the prototype aircraft. The goal is to identify stiffness-enhancing structural design changes, with minimum increase in weight, which allow the use of RAM while preserving the stiffness of the prototype aircraft.

Nine structural modifications to the tailcone were developed conceptually, then analyzed. NASTRAN analysis showed that the total effect of these modifications was to increase the torsional stiffness by 12 percent with respect to the baseline aircraft with graphite on the outer mold line. It is shown that the addition of radar absorbing material (RAM) to the outer skin of this modified model costs only a six percent reduction in torsional stiffness from baseline values as compared to a 24 percent reduction in tailcone stiffness for adding the same amount of RAM were these structural modifications not incorporated in the design. In other words, the design modifications developed in this work increased the torsional stiffness by 18 percent with respect to the baseline aircraft with Kevlar on the outer mold line (OML).

These results were presented verbally to the Army and in detail in the thesis work carried out by MAJ Tobin and MAJ Shoop. A summary of the year's work is given in the referenced report by Professors Wood, Danielson, and Gordis.

NPS students participated actively in this program. U.S. Army CPT Pat Mason joined the Sikorsky Dynamics Group under Mr. Bob Blackwell for a 1997 summer internship in which he worked on Comanche vibrations. At the end of the summer, Sikorsky sent him to West Palm Beach to witness the Comanche flight test program and he even had the opportunity to fly as co-pilot in the S-76 helicopter that serves as the chase aircraft for the Comanche. MAJ Vince Tobin, who had interned at Sikorsky during the summer of 1996, completed his thesis on the Comanche and graduated in June with distinction. MAJ Brian Shoop extended the work of MAJ Tobin to encompass the tailcone aft of the landing gear bay bulkhead. He completed his thesis and graduated in September.

PUBLICATION:

Wood, E. R., Danielson, D. A., and Gordis, J. H., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," Report submitted to Comanche Program Manager's Office.

PRESENTATIONS:

Wood, E.R. and Danielson, D.A., "NPS Helicopter Program and Comanche Work," San Francisco Bay Area Chapter of the American Helicopter Society, Moffett Field, CA, 20 February 1997.

Wood, E.R., "Helicopter Programs at NPS," Los Angeles Chapter of American Helicopter Society, Los Angeles, CA, 15 May 1997.

THESES DIRECTED:

Shoop, B. P., "Structural Design Analysis of the Tail Landing Gear Bay and the Vertical/Horizontal Stabilizers of the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, September 1997.

Tobin, V. M., "Analysis of Potential Structural Design Modifications for the Tail Section of the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Processes and Structures, Computing and Software, Modeling and Simulation, Manufacturing Science and Technology, Other (Design)

KEYWORDS: Helicopter, Rotorcraft, Dynamics, Structures

ADVANCED HELICOPTER TECHNOLOGY FOR SPECIAL OPERATIONS

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: Institute for Joint Warfare Analysis-Naval Postgraduate School

OBJECTIVE: To provide proof-of-concept helicopter modifications to Special Operations OH-6A derivative helicopter for increase in agility and power available and decrease in vibration and noise using intermittent higher harmonic control (HHC). To conduct a limited full-scale HHC flight test program for verification.

SUMMARY: From 1976 through 1985, NASA and the Army sponsored extensive research in HHC for helicopters. The resulting OH-6A flight test program (1982-84) showed large payoffs in noise, performance and vibration. For noise, it has been shown that HHC provides the capability to reduce and tailor the main rotor noise signature. For performance, it has been shown that HHC has the potential to provide a 10% improvement in hover, increasing up to a 20% improvement at 60 knots. For vibration, up to 90% reduction at n/rev can be realized throughout the aircraft. Since the 1985 time frame, there has not been any flight testing, but basic research into HHC has continued at leading aeronautical laboratories in both the U.S. and Europe (NASA, U.S. Army, DFLR, and ONERA).

This program makes the case that for military and research purposes, HHC flight testing should be resumed again. The agency to conduct the flight test evaluation is Special Operations Command. Whereas the initial OH-6A program focused on vibrations the proposed future program will incorporate three HHC derivative active control systems in one aircraft. The three derivative systems are: (1) low noise-stealth, (2) low vibrations, and (3) performance. Since components of the prototype system still exist, costs can be kept low by modifying a helicopter that is an operational OH-6A derivative.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Aerospace Propulsion and Power, Battlespace Environments, Computing and Software, Sensors, Modeling and Simulation, Other (Active Controls, Stealth)

KEYWORDS: Helicopters, Stealth, Rotary Wing, Special Operations Warfare, Joint Warfare Modeling and Simulation

GROUND/AIR RESONANCE SIMULATION OF HELICOPTER ROTOR SYSTEMS BASED ON FULL NON-LINEAR EQUATIONS OF MOTION

E. Roberts Wood, Professor
LCDR Robert L. King, Lecturer
Department of Aeronautics and Astronautics
Sponsor: Sikorsky Aircraft and National Rotorcraft Technology Center

OBJECTIVE: Professor Wood and LCDR King continued the original thesis work of LT Christopher S. Robinson in the area of nonlinear helicopter rotor dynamics. As hingeless helicopter main rotors become more commonplace, a need has arisen for a rotor simulation tool that will accurately model nonlinear mechanical properties so that these nonlinearities may be exploited to the helicopter's advantage. Tasks in this research included the formulation of a MAPLE“ based symbolic processing program that formulated nonlinear equations of motion given energy expressions for helicopter rotor model degrees of freedom. SIMULINK“ based computer simulations were developed from the equations of motion derived by the symbolic processor.

SUMMARY: This research has reported on a new method for formulating the full non-linear equations of motion for ground/air resonance stability analysis of helicopter rotor systems. A full set of non-linear equations was developed by Lagrangian approach using the well-known MAPLE“ symbolic processing software for expanding the equations. The symbolic software was further utilized to automatically convert the equations of motion into C, Fortran or MATLAB“ source code formatted specifically for numerical integration. The compiled C or Fortran code was then accessed and numerically integrated by the dynamic control simulation software, SIMULINK“. SIMULINK“ then applied a Runga-Kutta integration scheme to generate time history plots of blade and fuselage motion. The method was used to explore the effects of damping non-linearities, structural non-linearities, active control, individual blade control (IBC), and damper failure on air/ground resonance. Damping levels were determined from the time history plots by a MATLAB“ program, which used the Moving Block Technique for determining critical damping levels from the coupled rotor-fuselage response.

For validation, the analysis was compared with Coleman's classic theory and was also applied to representative cases that included: (1) The classic instability on isotropic supports; (2) The case of one blade damper inoperative; and (3) The case of one blade damaged by a ballistic strike.

PUBLICATIONS:

Robinson, C.S., Wood, E.R., and King, R.L., "Analysis Of Helicopter Rotor Instabilities Using Symbolic Processing and Control System Dynamics Software," *Proceedings of the 23rd European Rotorcraft Forum*, Paper No. 12, Dresden, Germany, 16-18 September 1997.

Robinson, C.S., Wood, E.R., and King, R.L., "Ground/Air Resonance Simulation of Helicopter Rotor Systems Based on Full Non-Linear Equations of Motion," *Proceedings of the Seventh International Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems*, Washington University, St. Louis, MO, 14-16 October 1997.

CONFERENCE PRESENTATIONS:

King, R.L., "Presentation of NPS Ground/Air Resonance Work to Date," U.S. Army Aeroflightdynamics Laboratory, Moffett Field, CA, June 1997.

Robinson, C.S., Wood, E.R., and King, R.L., "Analysis of Helicopter Rotor Instabilities Using Symbolic Processing and Control System Dynamics Software," Paper No. 12, 23rd European Rotorcraft Forum, Dresden, Germany, 16-18 September 1997.

Robinson, C.S., Wood, E.R., and King, R.L., "Ground/Air Resonance Simulation of Helicopter Rotor Systems Based on Full Non-Linear Equations of Motion," Seventh International Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems, Washington University, St. Louis, MO, 14-16 October 1997.

THESIS DIRECTED:

Robinson, C.S., "Modeling and Analysis of Helicopter Ground Resonance Utilizing Symbolic Processing and Dynamic Simulation Software," Engineer's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Materials, Processes, Structures, Modeling and Simulation

KEYWORDS: Rotorcraft, Helicopter, Ground/Air Resonance, Damperless, VTOL, MAPLE, SIMULINK, Nonlinear Simulation and Control

TESTING AND ANALYSIS FOR P-3 AIRCRAFT

Edward Wu, Professor
Department of Aeronautics and Astronautics
Sponsors: Naval Air Systems Command and Naval Postgraduate School

OBJECTIVE: The overall objective of these P-3 structural integrity programs is t provide increased reliability against failure during the service lifetime. Since fatigue testing, which is time consuming and destructive, cannot be conducted on a large scale, the existing methodology is based on the statistics of few samples. Many assumptions of uncertain validity are required to utilize such statistical data. A probabilistic approach developed by Coleman utilizing a convolution integral to assess damages resulted from different load history. The Naval Postgraduate School can contribute to the life extension program through the evaluation of conventional methodology and the formulation of modern damage accumulation to supplement the conventional fatigue analysis from constant amplitude load history to spectrum load history and to extend the prediction to include the life variability.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: P-3, Structural Integrity, Fatigue Analysis

BASIC SCIENCE AND DATABASE FOR COMPOSITE RELIABILITY AND LIFE PREDICTION

Edward Wu, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: To provide analytical and experimental databases for the definitive modeling of an appropriate composite reliability function addressing both strength and strength aging of composites materials and structures.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Composites, Composite Reliability